

EFFECT OF ECCENTRICITY PIN GEOMETRY ON THE FABRICATION OF SURFACE COMPOSITE (AL6061-T6 /SiC) BY FRICTION STIR PROCESSING

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ABSTRACT

This research investigates the effect of three types of friction stir processing (FSP) tool with a pin eccentricity of 0, 0.5 and 1mm on the fabrication of AA6061-T6/SiC surface composites (SCs). The pin eccentricity induced severe plastic deformation in the nugget zone or composite region, which resulted in the enhanced material flow. FSP experiments were performed with a constant tool speed of 1000 rpm, traverse feed of 20 mm/min and the tilt angle of 3°. The experiments revealed that 0.5mm eccentric tool produced better surface composites with uniform particles distribution and mechanical properties

KEYWORDS: Eccentric Pin Tool, HEAT Input, Uniform Distribution & Surface Composite

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INTRODUCTION

Aluminium (Al) based SC's possess light weight, high strength and better wear resistance, as compared with conventional Al-based alloys. SC's are fabricated by secondary phase particles on the surface of the matrix, while the base metal retains the actual properties unaltered [1]. Recently, surface modification technique namely, Friction stir processing (FSP) is proved to be the best technique to fabricate surface composites[2]. In this process, the tool plays a vital role to generate a sufficient amount of heat which causes severe plastic deformation. But, particle distribution is the major issue of this process. To overcome the issue, many attempts have been carried out by various researchers. Essa et al. attempted in FSW by using pin eccentricity tool, and proved a dynamic orbit path of the pin produced better joint properties[3]. So, in this study also the similar concept has been implemented in FSP for fabrication of SC to achieve uniform distribution of particles. Three tools have been fabricated with a pin eccentricity of 0,0.5,1 mm to produce Al 6061-T6- SiC SC with better particles distribution, mechanical properties and wear properties.

EXPERIMENTAL METHODS

A 5mm thick plate of Al6061-T6 was used as a matrix with SiC as secondary phase particles. FSP experiments were carried out with a tool speed of 1000 rpm and traverse feed of 20mm/min. FSP tool is having shoulder dia of 25mm, Pin dia of 6 mm and length of 3mm (Figure1a). The experiments were performed on a 4-axis FSW machine (BiSS-ITW0). Optical microscope and SEM was employed for microstructural studies using modified Poulton's reagent to reveal the grain structure. Microhardness of the SC was evaluated using a 200g load for 10s dwell time. The tensile test was conducted as per the ASTM-E8 with the strain rate of 1mm/min. The sliding wear

behaviour was studied via a pin on disk tribometer as per the ASTM-G99-04 standard, at a sliding velocity of 1m/s a loaded of 20N and a sliding distance of 1000m.

RESULTS AND DISCUSSIONS

Energy per unit length of the pass was calculated based on the equation 1&2, and the values are tabulated in table1. The values are increasing as the tool pin eccentricity increases under the same FSP parameters. The maximum temperature, which was calculated at the bottom of the pin was getting decreased by increasing the pin eccentricity[3, 4]. As the eccentricity increases, the pin travel path is getting enlarged (Figure1b). Hamilton predicted that appropriate energy input for nugget zone is in the range of 800J/mm to 2000J/mm[5]. So, it is clear that all tools generated sufficient energy for the deformation. Figure 1(c) shows the defect-free nugget zone of SC's fabricated by various eccentric tools.

$$E_{eff} = \frac{2\omega \cdot F \cdot \mu}{3\theta \cdot r_s^2} \left[\frac{(r_s^3 - r_p^3)}{\cos \theta} + 3h_p (r_p + e)^2 + ((r_p + e)^3 - e^3) \right] X \frac{h_p}{t} \quad (1)$$

$$\frac{T_{Max}}{T_s} = 2 \times 10^{-4} E_{eff} + \frac{0.5 \times r_p^2}{(r_p + e)^2} \quad (2)$$

E_{eff} - Effective heat generation (J/mm), r_p - radius of pin (mm), r_s - radius of shoulder (mm), h_p - height of pin (mm), e - eccentricity of pin (mm), μ - coefficient of friction, ω -angular velocity (rad/s) θ -shoulder concave angle ($^\circ$) v -welding feed (m/s) F - Plunge force (N), T_{max} -maximum temperature ($^\circ$ C) T_s -solidus temperature ($^\circ$ C)

Table 1: Properties of Base Material and Al6061-T6/SiC SC

	E_{eff} in J/mm	Max. Temperature in Celsius	Micro Hardness (Hv _{0.2})	Tensile Strength (MPa)	Elongation (%)	Co Efficient of friction	Weight Loss (mg)
Base material	--	--	63±1.89	252	27.6	0.37	0.094
0 mm pin Eccentric	1.065X10 ₃	420.07	141±4.23	245	7.7	0.32	0.009
0.5 mm pin Eccentric	1.587X10 ₃	401.69	146±4.38	290	13.8	0.52	0.005
1 mm pin Eccentric Tool	1.967X10 ₃	386.52	137±4.11	185	22.43	0.36	0.007

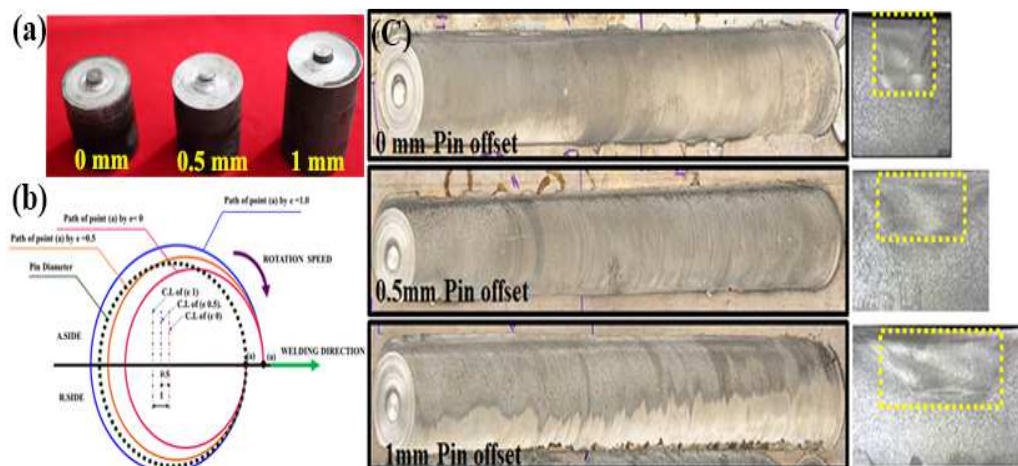


Figure 1: (a) Eccentric Tool (b) Schematic Eccentric Pin Flow Path (c) Processed Specimen and Macrographs

Uniform distribution of particles has been achieved by all tools. The particles distribution shows that the nugget zone is getting wider owing to increased eccentricity. SC without any defects was produced with the matrix, strongly bonded by particles, which are required to enhance the load bearing capacity of components [6]. The 1mm pin eccentric tool produced more energy and low temperature, due to which particles are not uniformly distributed (Figure 2a). Figure 2b illustrates the hardness values of composites. The maximum hardness (146Hv0.2) was obtained in SC produced by the 0.5mm eccentric pin. In all the cases, the increase in hardness is observed at nugget zone due to the presence of secondary particles (Figure 2b). Further, the increased hardness values of the FSP specimens is attributed to the grain refinement and distribution of particles [7].

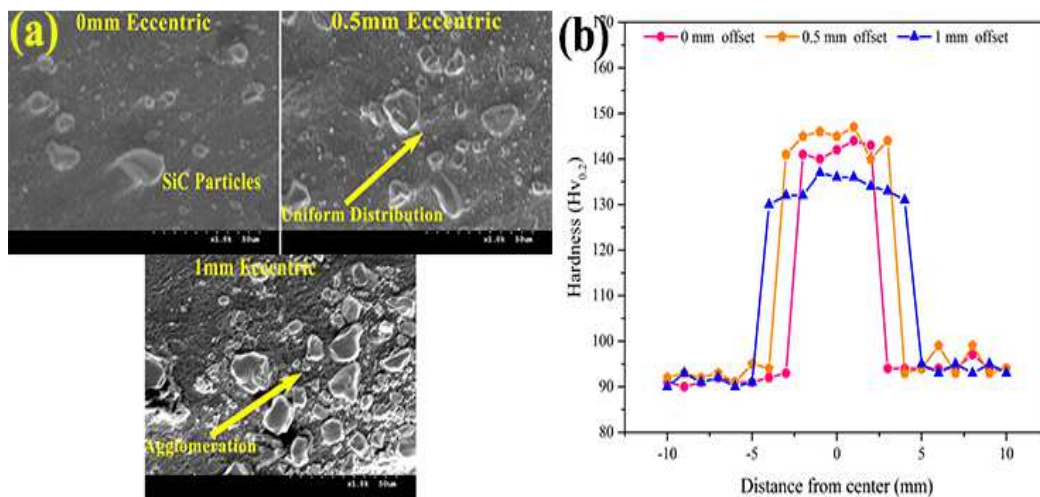


Figure 2: (a) SEM Images of SC (b) Hardness of SC using Eccentric Pin

Figure 3a depicts the stress-strain plot of the base material and surface composites. It can be seen that the yield strength of the SC is higher than the base material. The 0.5mm pin eccentric condition results in better yield strength and ductility (Table 1). While FSP is performed, Secondary particle addition in the matrix encourages dynamic recrystallization and pinning effect of particles on a matrix, which hinders the grain growth. Also, the presence of particles enhances the ultimate strength, because the high stress is needed to form the crack between the matrix and particle interfaces. The ductility is reduced as seen in Figure 3a for the SCs than the base material owing to the addition of particles [8]. Figure 3(b-e) illustrates the fracture images of the tensile specimen from SEM. Larger voids and dimples on the fracture zone can be viewed in the base material as shown in Figure 3b. Whereas, SCs exhibit smaller dimples and quasi-cleavage in comparison to the base material indicating mixed mode fracture. The smaller voids and dimples can be credited to the refinement of grains, while the dynamic recrystallization and uniform distribution of the particles in the matrix as displayed in Figure 3c, d, and e.

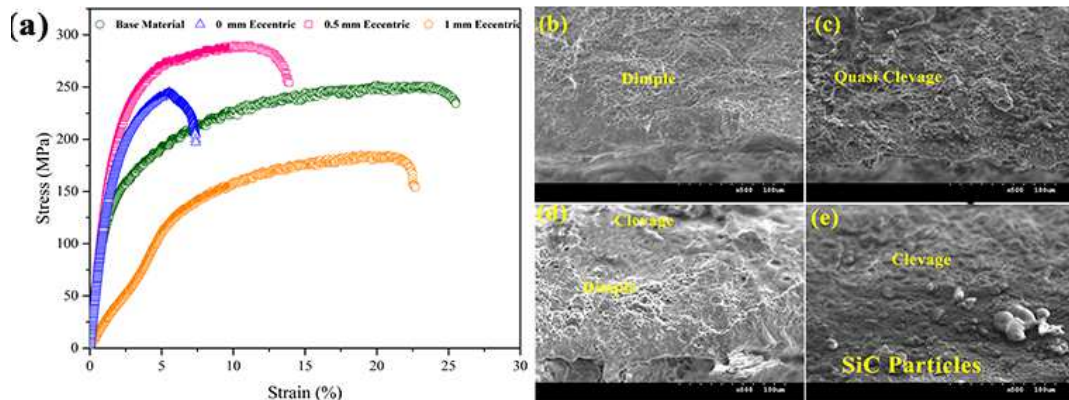


Figure 3: (a) Stress-Strain Curve of SC (b-e) Fractography Images of the Fractured Specimen

Wear behaviour for the base material and SCs is presented in Table 1. It is revealed that the wear resistance of SC is enhanced (Figure 4a). The factors influencing the enrichment of the wear resistance are the uniform distribution of the particles during the better stirring of the 0.5 mm eccentric pin tool. The fine grains and enriched hardness improved wear properties [7]. Figure 4(b-e) shows the fractography of the worn-out surfaces of the base material and SCs. In the figure 4b, minimum damage to the surface is showed along the sliding path. The long continuous grooves developed on the matrix results in ploughing action, and left the material into ridges along the sides of the grooves. This is because of the presence of secondary particles, limiting the flow of the material during the wear process [8]. Because of this, the worn-out region expresses both the delamination and abrasive mechanism of wear. Owing to the high hardness, good bonding of the particle with the matrix and grain refinement, the plastic deformation is at minimum (Figure 4d).

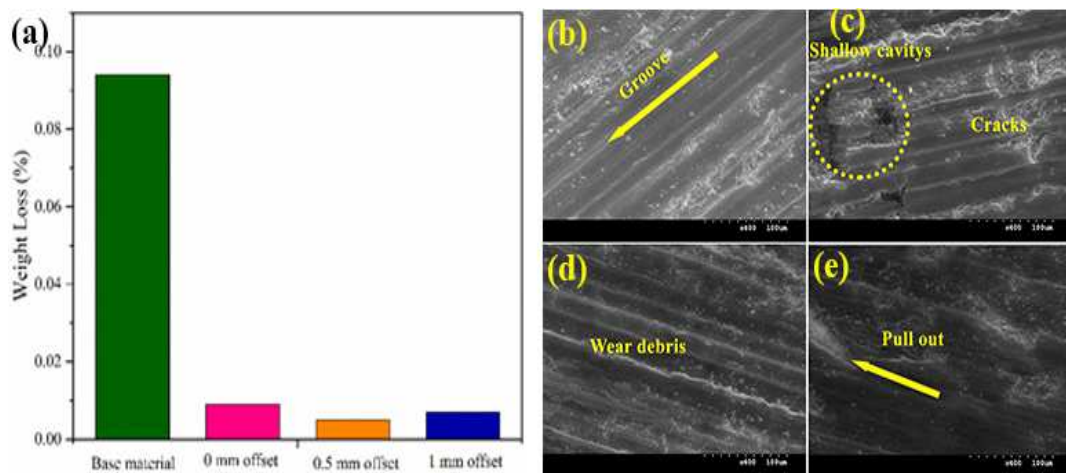


Figure 4: (a) Weight Loss of SC (b-e) SEM Images of Worn-Out Surfaces

CONCLUSIONS

The SC of Al 6061-T6/SiC was fabricated using an eccentric pin of 0, 0.5 and 1 mm FSP tool. The 0.5mm eccentric pin tool achieved the SC with a uniform distribution of particles, better energy/length and heat generation appropriate to stirring. Enriched microhardness was observed for SC, in comparison to the other composites and base material. The surface composite's tensile strength was improved. The addition of secondary particles obstacles the dislocations movement. The wear rate decreased for all the SCs specimens than the base material, owing to a uniform dispersion of particulates and grain refinement.

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